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Response of Bush Snap Beans (*Phaseolus vulgaris* L.) to Irrigation and Plant Density[1]

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Abstract. **Yields of snap bean pods were increased by irrigation and plant density in 4 field experiments. Highest yields were obtained with the −0.6 bar soil water potential regime which represented removal of 40–45 percent of the available soil water at 30 cm depth. Yields were lowest with the −2.5 bars soil water potential which represented 65–70 percent water removal. An average of 60 percent more water applied to the −0.6 bar than the −2.5 bars treatment increased yields approximately 54 percent. Yields were usually intermediate with the −1.0 bar soil water potential representing 50–55 percent available soil water removal. Two cultivars were used in 2 of the experiments and responded differently to irrigation. Yield of 'Oregon 1604' was higher than that of 'Galamor' with −0.6 bar soil water potential but was lower than 'Galamor' with −2.5 bars. Yield of 'Oregon 1604' averaged 27 percent higher in square arrangement than in 91 cm rows and the increase was greater for the high than for the low population density when compared in 1 experiment. Yield was 20 percent higher for high density of 43.0 plants/m^2 than for low density of 21.5 plants/m^2. Yields of 2 cultivars in 2 experiments averaged 67 percent higher in high density (40–57 plants/m^2) than in low density (20–33 plants/m^2) plantings. There were no consistent irrigation × density interactions. Usually there was a more rapid depletion of soil water for high density than for low density. Fiber in canned sieve size 5 pods was higher in 'Oregon 1604' at −2.5 bars soil water potential than for 'Galamor', but at the −0.6 bar soil water potential regime, the amount of fiber was similar in the 2 cultivars. Percent of pod weight attributed to seed and percent fiber were usually highest at −2.5 soil water potential.**

Several investigators have shown that bush snap bean yields are increased by higher population densities and/or closer row spacings (1, 7, 9, 11). However, there is limited research on irrigation requirements for high density plantings. Smittle (13) found that responses of 2 plant populations to irrigation and N fertilization were similar. Highest yields were obtained with a combination of high plant population, more frequent irrigation, and highest N rate.

The objective of the present study was to evaluate the interactive effects of irrigation treatments on bush bean cultivars at low (conventional) and high plant population densities, when effects were measured in terms of soil water potential, yield, and sieve size distribution of pods, and quality of processed pods.

Materials and Methods

Four field experiments were conducted during 1977–78–79 at the Oregon State University Vegetable Research Farm on a Chehalis silty clay loam soil that had an average water holding capacity of 6.4 cm per 0–30 cm depth. Details of the experimental site were described previously (4, 8). The low, medium, and high soil water or irrigation treatments were based on soil water potentials of −2.5, −1.0, and −0.6 bars, respectively, at which time plots were irrigated by overhead sprinklers, and represented available soil water removal of about 65–70, 50–55, and 40–45 percent. Scheduling of irrigation was based on gypsum electrical resistance soil moisture blocks placed between plants in 91 cm rows of the cultivar 'Oregon 1604'. Blocks at a 15 cm depth were used for scheduling the first 1 or 2 irrigations while those at 30 cm depth were used for later irrigations (12). Block readings at 15, 30, and 45 cm were made 3 times weekly but only the data from the 30 cm depth are reported.

Irrigation treatments were main plots (6 m × 6 m) with plant densities (row spacings) and cultivars as subplots. Number of irrigations and amounts of water applied in Expts. 1, 2, and 3 are shown in Table 2 and in Fig. 1 for Expt. 4. Fertilizer at 56 kg N, 74 kg P, 47 kg K/ha was banded in both 15 and 91 cm rows at planting in Expts. 1, 2, and 3. Fertilizer at 107 kg N, 142 kg P, 90 kg K/ha was broadcast and incorporated with a disc harrow before planting in Expt. 4. Standard methods were used for weed and insect control. Specific treatments within each experiment are covered separately below.

Expt. 1 (1977). Two irrigation treatments, −0.6 and −2.5 bars soil water potential, replicated 4 times, were main plots with subplots of 'Oregon 1604' planted in 15 cm rows (high density) and 91 cm rows (low density) on June 9. Plant populations averaged 65 plants/m^2 in 15 cm rows (15 × 10 cm) and 30 plants/m^2 in 91 cm rows (91 × 3.7 cm). Plant density and rectangularity were both changed when row spacings were narrowed and thus density and arrangement were confounded. All plots were irrigated June 10 with 13 mm water. Total rainfall from planting through harvest was 8 mm. First bloom (when about 10 percent of plants had open flowers) was July 21, 40 days after planting. Three once-over harvests by hand to simulate machine harvest were made on August 10, 12, and 15. Harvested area was 3.0 m length from 91 cm rows and 3.0 m^2 from 15 cm rows. Pod weight of sieve sizes 1–4 for the several harvests of the various treatments ranged from 30 to 70 percent of the total pod weight. Pods from all replications of a

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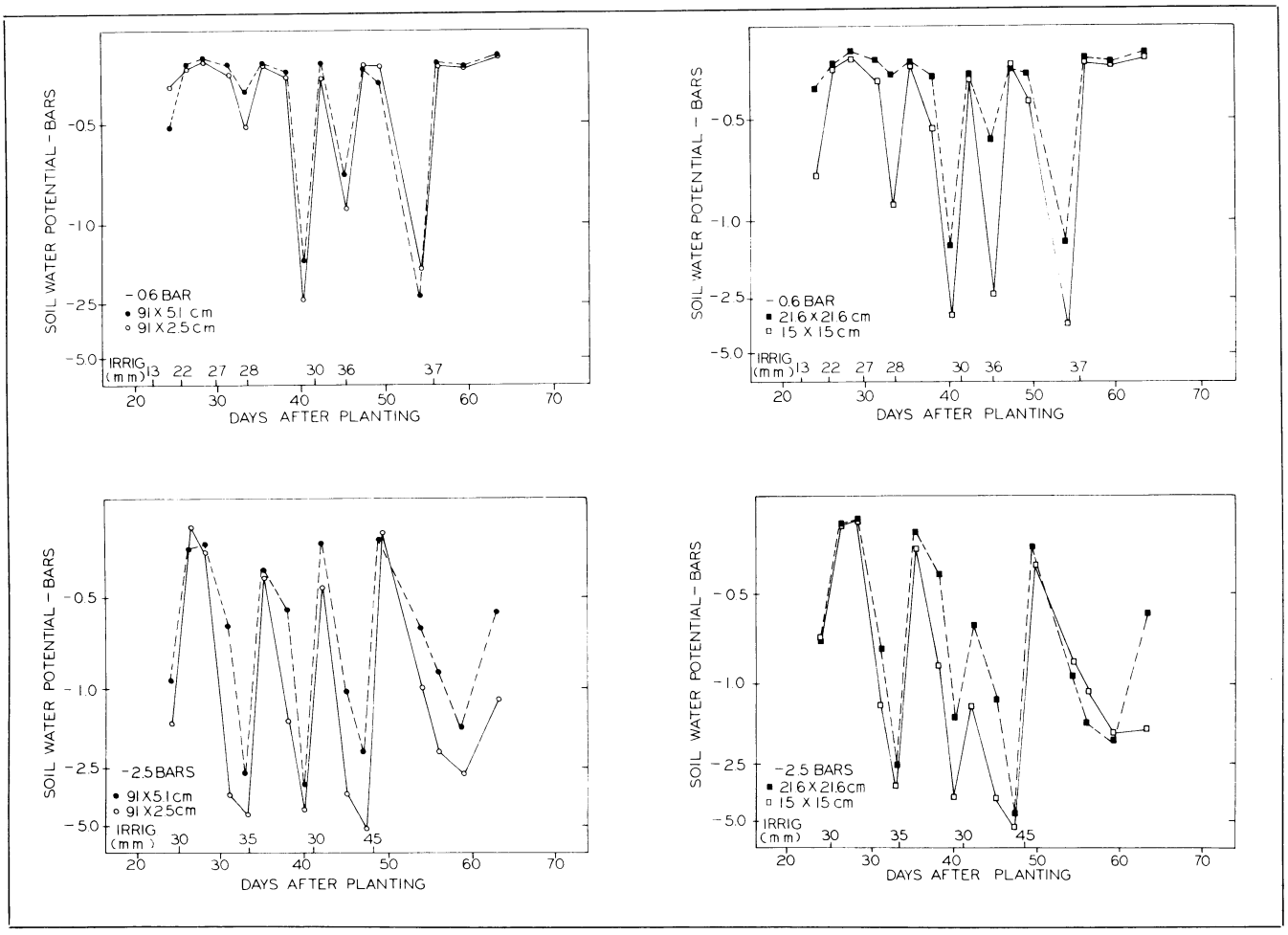

Fig. 1. Effects of two irrigation treatments (−0.6 and −2.5 bars soil water potential) and four spacing treatments (2 densities, 2 arrangements) on soil water potentials at 30 cm depth, Expt. 4. Soil water potential is a translation from a linear scale of meter readings.

given treatment were bulked for sieve size grading. Yield and sieve size data from the several harvests were usually combined and averaged.

Crop values were calculated, in some cases, based on prices of \$149/MT for pods sieve sizes 1–4 and \$71/MT for pods sieve size 5 and larger diameter. The equation for pod value was that given by Stansell and Smittle (14):

$$\$/\text{ha} = \text{MT/ha}\,(77.16\,P/100 + 71.65)$$

where P equals the percent of pods of sieve sizes 1–4.

Expt. 2 (1978). Three irrigation treatments (−0.6, −1.0, and −2.5 bars soil water potential) replicated 4 times, were main plots. 'Oregon 1604' and 'Galamor' were planted on June 7 in 15 and 91 cm rows. Plant populations averaged 40 plants/m^2 in 15 cm rows (15 × 16.7 cm) and 20 plants/m^2 in 91 cm rows (91 × 5.5 cm). All plots were irrigated with 20 mm water just after planting. Rainfall from planting through harvest (June 7–August 14) was 36 mm. First bloom was on July 19 for 'Oregon 1604', 42 days after planting, and on July 21 for 'Galamor', 44 days after planting. Once-over hand harvests were made on 'Oregon 1604' on August 4, 7, and 9 and for 'Galamor' on August 8, 10, and 14, similar to procedures in Expt. 1. In addition, samples of sieve size 5 pods were canned (harvest no. 2) and quality measurements of percent seed and percent fiber were determined (8).

Expt. 3 (1979a). Three irrigation treatments, the same as in Expt. 2, were replicated 4 times. 'Oregon 1604' and 'Galamor' were planted in 15 cm and 91 cm rows on June 11. Plant populations averaged 57 plants/m^2 in 15 cm rows (15 × 11.7 cm) and 33 plants/m^2 in 91 cm rows (91 × 3.3 cm). All plots were irrigated on June 15 with 25 mm water. Rainfall was 28 mm from planting through harvest. First bloom was on July 22 for 'Oregon 1604', 41 days after planting, and on July 24 for 'Galamor', 43 days after planting. Harvest was on August 10 and 13 for 'Oregon 1604' and on August 14 and 20 for 'Galamor'. Sieve size 5 pods were canned and quality measurements determined as in Expt. 2.

Expt. 4 (1979b). Two irrigation treatments, − 0.6 and −2.5 bars soil water potential, were replicated 3 times. Plant population and planting arrangement of 'Oregon 1604' in 4 treatments were evaluated at the 2 soil water levels. Plant densities of 21.5 and 43.0 plants/m^2 were planted on the square and in 91 cm rows at the following spacings: 91 × 5.1 cm, 21.6 × 21.6 cm, 91 × 2.5 cm, and 15 × 15 cm. One replication (2 irrigation treatments) was hand planted each day on June 20, 21, and 22. All plots were irrigated on June 22. Irrigation scheduling was based on soil water potentials determined by gypsum blocks placed in 91 cm rows. Rainfall from planting through harvest (June 20–August 24) was about 46 mm with most of it occurring during the 10 days before harvest. First bloom was about 44–45 days after planting. All replications were harvested on August 24, 65–67 days after planting. Thirty plants were harvested from each treatment of each replication in a single harvest. Yields were adjusted to a common 50

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Table 1. Effects of irrigation treatments (soil water potential), plant density, and plant arrangement on yield of 'Oregon 1604' bush snap beans, Expt. 4.

Irrig. treat.	Yield (MT/ha)						
	Low density (21.5 plants/m^2)		High density (43.0 plants/m^2)		Irrig. x Arrgmt. means		Irrig. treat. Means
	91 x 5.1 cm	21.6 x 21.6 cm	91 x 2.5 cm	15 x 15 cm	91 cm rows	Square	
-2.5 bars	12.7	13.5	14.6	17.1	13.7	15.3	14.5
-0.6 bar	13.6	18.7	15.7	22.7	14.7	20.7	17.7
Density x Arrgmt.	13.2	16.1	15.2	19.9			
Density means	14.6		17.5				
Arrgmt. means					14.2	18.0	

LSD 5% Irrig. x arrangement=2.4; LSD 5% Density =1.7; LSD 5% Arrangement=1.7; LSD 5% Irrig. treat.=NS.

percent sieve sizes 1–4 basis for all treatments using a factor of .11 MT/ha adjustment for each 1 percent change in sieve sizes 1–4.

Results

Yield. Yields of pods from the −0.6 bar soil water potential treatment ranged from 23% (Expt. 4) to 95% (Expt. 1) above those from the −2.5 bars soil water potential treatment in the 4 experiments, population densities, harvest dates and cultivars pooled (Tables 1 and 2). An average of 60% more water applied to the −0.6 bar than the −2.5 bar treatment increased yields about 54%. Yield from the −1.0 bar treatment exceeded that from −2.5 bar in Expt. 2 but not in Expt. 3 with combined plant densities. Crop values were highest at the −0.6 bar irrigation treatment and at high population density in Expts. 1, 2, and 3 (Table 2).

Yield was 20% higher from the high population, 43.0 plants/m^2, than from the low population, 21.5 plants/m^2 in Expt. 4 (Table 1). Yield of plants in square arrangements averaged 27% higher than from 91 cm row plantings and the increase was greater for the high population (31%) than for the low population (22%). Yield of the 2 cultivars in Expts. 2 and 3 averaged 67% higher in high density (15 cm rows) than in low density (91 cm rows) while yield of 'Oregon 1604' was 10% higher for high than low density in Expt. 1 (Table 2).

Yields from harvest dates were usually pooled but effects of harvest dates, irrigation treatments, and plant density on 'Oregon 1604' in Expt. 2 are illustrated in Table 3. Range in sieve size distribution for the 3 dates was larger for the −0.6 and −1.0 bar soil water potential treatments than for −2.5 bars. The range in percentage size distribution was highest in high density planting at the −0.6 bar treatment. Yield averaged 101% higher in the −0.6 bar treatment (all harvest dates pooled) than for −2.5 bars while crop value was 118% higher at −0.6 than at −2.5 bars. Yield of high density planting was 57 percent greater for low density and crop value averaged 64% higher for high than low density reflecting the higher value for pods of smaller sieve sizes.

Certain interactions also affected yield. In Expts. 2 and 3 cultivars responded differently to irrigation in that yield of 'Oregon 1604' was higher than for 'Galamor' in the −0.6 bar soil water potential treatment but lower than 'Galamor' in the −2.5 bars treatment (Table 4). Also, 'Oregon 1604' showed a significantly greater increase in yield (3.8 times as great) than did 'Galamor' when irrigation was changed from −2.5 and −0.6 bars.

Irrigation × arrangement interaction was significant in Expt. 4 (Table 1) where yield of plants in the square arrangement was not significantly different from 91 cm rows at the −2.5 bar soil water potential but at −0.6 bar plants in square arrangements yielded significantly more (42 percent) than in 91 cm rows. There was no significant irrigation × density interaction since yield response of the 2 densities (arrangements pooled) to irrigation treatments was similar. Yields for the 21.5 and 43.0 plants/m^2 densities were 13.1 and 15.8 MT/ha, respectively for −2.5 bars and 16.2 and 19.2 MT/ha for the −0.6 bar soil water potential treatment.

Percent seed and percent fiber in canned pods. Percent seed and fiber in sieve size 5 pods was usually lower at the high soil water level than at the low level but this was not consistent (Table

Table 2. Effects of irrigation treatments and plant densities on pod yield, sieve size distribution, and crop value of snap beans (cultivars pooled in Expts. 2 and 3).

Irrig. treat. -bars SWP[z]	Irrig. no.	Water appl. (mm)	Yield of pods (MT/ha)[y]			Sieve sizes 1-4(%)		Value ($/ha)	
			Low density	High density	Irrig. trt. means	Low density	High density	Low density	High density
Expt. 1									
-2.5	3	122	11.6	12.1	11.8	68	77	1440	1586
-0.6	7	231	21.7	24.4	23.0	61	62	2576	2916
Expt. 2									
-2.5	4	167	5.4	9.8	7.6	67	69	666	1224
-1.0	6	185	6.7	12.1	9.4	64	69	811	1511
-0.6	9	269	9.9	17.0	13.4	62	70	1183	2136
Expt. 3									
-2.5	4	145	9.2	16.1	12.6	44	48	972	1750
-1.0	6	185	9.6	14.3	12.0	42	51	999	1598
-0.6	8	228	12.8	18.8	15.8	39	52	1302	2101

[z]Soil water potential, 30 cm depth.
[y]Statistical significance for yield of pods at 5%(*) or 1% (**) level – Expt. 1, Irrigation**,Density*; Expt. 2, Irrigation**, Density **; Expt. 3, Irrigation**, Density**.

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Table 3. Effects of irrigation treatments, plant density, and harvest date on yield, sieve size distribution, and crop value of 'Oregon 1604' bush snap beans, Expt. 2.

Irrig. treat. -bars SWP[z]	Harvest[y]	Yield (MT/ha) Low density	Yield (MT/ha) High density	Sieve sizes 1-4 (%) Low density	Sieve sizes 1-4 (%) High density	Value ($/ha) Low density	Value ($/ha) High density
-2.5	1	3.1	4.9	59	66	363	601
	2	5.6	8.7	52	60	626	1026
	3	7.2	10.8	49	58	788	1257
Avg (-2.5 bars)		5.3	8.1	53	61	592	961
-1.0	1	3.8	5.8	63	73	457	742
	2	9.0	12.5	54	57	1020	1445
	3	9.4	15.4	50	53	1036	1733
Avg (-1.0 bar)		7.4	11.2	56	61	838	1307
-0.6	1	5.6	10.5	70	87	704	1457
	2	11.9	18.8	63	73	1431	2406
	3	15.9	24.2	39	42	1618	2518
Avg (-0.6 bar)		11.1	17.8	57	67	1251	2127
Plant density means		7.9	12.4	55	63	894	1465

[z]-bars soil water potential, 30 cm depth.
[y]Once-over harvest on Aug. 4,7, and 9 – 58, 61, and 63 days after planting.

5). Irrigation treatment had no significant effect on percent seed in 'Galamor' but did for 'Oregon 1604'. 'Galamor' pods were higher in percent seed than 'Oregon 1604'. Percent seed in pods was 6.03 from high density compared to 5.40% in low density (irrigation treatments and cultivars pooled).

Fiber was higher in 'Oregon 1604' than 'Galamor' pods at the −2.5 bars soil water potential but at −0.6 bar soil water potential fiber content of the cultivars was not different. Fiber concentration of 'Galamor' pods was unaffected by irrigation while fiber of 'Oregon 1604' was increased by water stress. There was no consistent effect of density on percent fiber in pods.

Soil water potentials. Soil water potentials in Expt. 4, shown in Fig. 1, had a greater similarity in pattern at a given population density than for similar arrangements. For example, patterns were more alike for 91 × 2.5 and 15 × 15 cm spacings than for 91 × 2.5 and 91 × 5.1 spacings. Soil water was depleted more rapidly during the drying cycle at high than at low population density.

Discussion

Highest yields of snap bean pods were consistently obtained at the highest soil water regime, −0.6 bar soil water potential, used in the 4 experiments. However, the irrigation frequency of 4 to 8 days used to maintain the high soil water level could potentially create a favorable microclimate for development of certain diseases such as white and grey molds, especially in high density (narrow row) plantings. Steadman et al. (15) found that white mold disease on 'Great Northern' dry beans was lower in 76 cm vs. 25 cm row spacings. Close row spacing of snap beans (30 cm vs. 91 cm) reduced air movement and increased relative humidity according to Crandall et al. (3). When periods of rainfall occurred after bloom (Expt. 4), some mold infection, though not severe, was apparent in all plots and was more abundant at the high moisture level and in square planting arrangements. However, in Expt. 1 when there was no rain after bloom, no mold infection was apparent in either irrigation treatment. No fungicides were applied for mold control in any of the experiments.

Yield responses did not give a clear indication of increased water needs or greater degree of moisture stress for plants at high densities compared to low densities but there was a trend for more rapid depletion of soil water in high density plantings. Smittle (13) reported higher yields of snap beans from 30 cm than from 91 cm rows but responses of the 2 row spacings to irrigation and N fertilization were similar.

Yield response for 'Oregon 1604' from increased irrigation level was greater than for 'Galamor'; however, canned sieve size 5 pods of 'Oregon 1604' contained more fiber than 'Galamor' at the low moisture level. It has been shown that in comparing the

Table 4. Effects of three irrigation treatments on yield of two cultivars of bush snap beans, Expts. 2 and 3 (low and high densities combined).

Expt.	Cultivar	Yield (MT/ha) Irrigation treatment -2.5	-1.0	-0.6	Cultivar avg.
2	Oregon 1604	6.7	9.3	14.5	10.2
	Galamor	8.6	9.3	12.4	10.2
	Irrig. avg.	7.6	9.4	13.4	
3	Oregon 1604	12.0	10.3	16.6	13.0
	Galamor	13.2	13.6	15.0	13.9
	Irrig. avg.	12.6	12.0	15.8	

Expt. 2. LSD 5% irrig. x cultivar=1.0; LSD 5% irrig. treat.=0.7; LSD 5% cultivar=NS.

Expt. 3. LSD 5% irrig. x cultivar=2.7; LSD 5% irrig. treat.=2.1; LSD 5% cultivar=NS.

Table 5. Effects of irrigation treatments on percent seed and percent fiber in sieve size 5 pods of canned snap beans (Expts. 2 and 3 combined; 2 plant densities pooled).

Irrig. treat. -bars SWP	Cultivar	Seed (%) Cultivar avg.	Seed (%) Irrig. avg.	Fiber (%) Cultivar avg.	Fiber (%) Irrig. avg.
-2.5	Oregon 1604	6.19	6.11	.066	.042
	Galamor	6.04		.018	
-1.0	Oregon 1604	4.29	5.20	.027	.022
	Galamor	6.12		.016	
-0.6	Oregon 1604	5.47	5.83	.016	.017
	Galamor	6.19		.018	
	LSD 5%	0.70	0.49	.013	.009

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same sieve size, a delay in harvest usually results in higher percentages of seed and fiber and probably will be more accelerated under conditions of moisture stress (5, 6, 10). Our results also suggest that 'Galamor' is better adapted to greater soil water stress conditions than is 'Oregon 1604'. 'Oregon 1604' was developed in the Oregon State University snap bean breeding program in which the irrigation regime was similar to the high irrigation treatment used in this study. Gabelman and Williams (5) reported differential responses of cultivars to irrigation treatments and suggested that it is highly desirable to test new cultivars under both good and poor irrigation conditions.

Earlier work (1, 2, 7, 9, 11) indicated that higher yield can be obtained with increases in population and/or changes in plant arrangement which is confirmed by the present results. Population density and plant arrangement effects on yield were additive in Expt. 4. Increased yields of high over low populations in Expts. 1, 2, and 3 were likely the result of both increased density and improved arrangement through use of narrow rows (more toward achieving a 1:1 rectangularity). Results from this study reinforce the concept that an integrated, broad-based approach in which many factors are considered is needed to obtain optimized cropping systems for bush snap beans.

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Effect of Gibberellic Acid and Seed Rates on Pepper Seed Germination in Aerated Water Columns[1]

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Additional index words. Capsicum annuum, fluid drilling

Abstract. **Seed germination of pepper (*Capsicum annuum* L.) in aerated water columns was accelerated and germination uniformity improved by using gibberellic acid (GA_3) at 6 μg/mg seed with 50 to 75 mg seed/ml of solution. Higher GA_3 rates in the aerated columns reduced germination percentage in some cultivars. Detrimental effects for GA_3 up to 6 μg/mg seed were not observed and in some cultivars speed of emergence and seedling growth was stimulated. GA_3 is economically feasible for use in germinating pepper seeds for sowing using the fluid drilling technique.**

Rapid and uniform germination is difficult to achieve with most pepper seed. Cultivars which usually have a high total percent germination do not exhibit uniformity in germination. Kanchan (9) reported that soaking pepper seed for 5 to 10 hr in GA_3 solutions stimulated germination. Other workers have reported stimulation of pepper seed germination using various techniques including polyethylene glycol and sodium hypochlorite treatments (6, 7, 14). GA_3 has been shown to stimulate seed germination in many species (1, 2, 10, 11, 12, 13).

It is essential to have a high percentage of germinated seed with uniform radicle length for fluid drilling (3, 4). Within a seed lot a few seeds produce radicles first and these often develop long radicles before the remaining seeds are at the proper stage of germination for fluid drilling. Long radicles (>4mm) on early germinat-

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